DETECTION OF UNNECESSARY TRAVERSING OF TRAFFIC FLOWS USING HISTORICAL VEHICLE ITINERARIES

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ABSTRACT

Our previous researches have shown that the throughput capacity of an individual traversing and transport network in general can be significantly increased by proper routing of traffic flows at in-grade traversing by means of minimization of unnecessary, thus avoidable, traversing in traffic flows. This can substantially increase the average speed, reduce the waiting times at traversing and reduce the adverse impact of the traffic on the environment and traffic safety.

In this paper a method is shown that utilizes recorded vehicle itineraries gathered from corporate fleet management and tracking systems. Vehicle locations obtained by GNSS are transformed into paths and introduced to spatiotemporal GIS database and processed through methods of stochastic analysis in order to detect and indicate points and intensities of unnecessary traversing of traffic flows. By analyzing the relations between the routes, the causes of unnecessary traversing may be determined and adequate measures to eliminate such a situation can be undertaken.

Keywords: Unnecessary traversing of traffic flows, vehicle itineraries, fleet management and tracking systems, spatiotemporal GIS database

1. INTRODUCTION

Interactions between traversing traffic flows at traversings are main causes of reduced throughput in transport networks. Avoiding the traversing and reduction of overlapping of traffic flows is one of the most significant factors that can be used to increase the traversing capacity. Relationships among the traffic flows in the form of traversing at traversings is most obvious in orthogonal one-way road networks, and are caused by incorrect routing and directions of traffic flow in the network. For advanced identification of traversings, modern IT solutions are used as a novel approach in research and visualization of this phenomenon, some of our researches on this topic has been shown in [1-4].

Y. Li, L. Jianxun, S. Daji, L. Xuan, and Qudong have stated that due to the nature of road traffic and massive scale of individual transportation, reduction of unnecessary traversing of traffic flow is particularly important in city centers [6]. The reduction of unnecessary traversing among the traffic flows as suitable approach which can be used to achieve the goal of creating a selection of few real and applicable solutions of traffic flow organization within the network is also shown in research by C. Hoong-Chor and S.-T. Quek [8].

2. PROBLEM DESCRIPTION

Unnecessary traversing of traffic flows can be explained as interaction between traffic flows which is not needed and can be avoided [1]**.** For example, if there are two zones, or two points in the network between whom traffic is running in opposite direction, the traffic flows should not influence or traverse one another. However, in real transport networks vehicle trajectories between opposing two zones do traverse. Simple representation of this phenomenon is shown on Figure 1. In example a) shown on Figure 1 flows "p" and "q" traverse in points N_1 and N_2. By simple rerouting of traffic (change in direction of one way streets) as shown in example b) on Figure 1. traversing in points N_1 and N_2 is avoided. This means that traversing of flows in example a) was avoidable thus being rated as unnecessary.

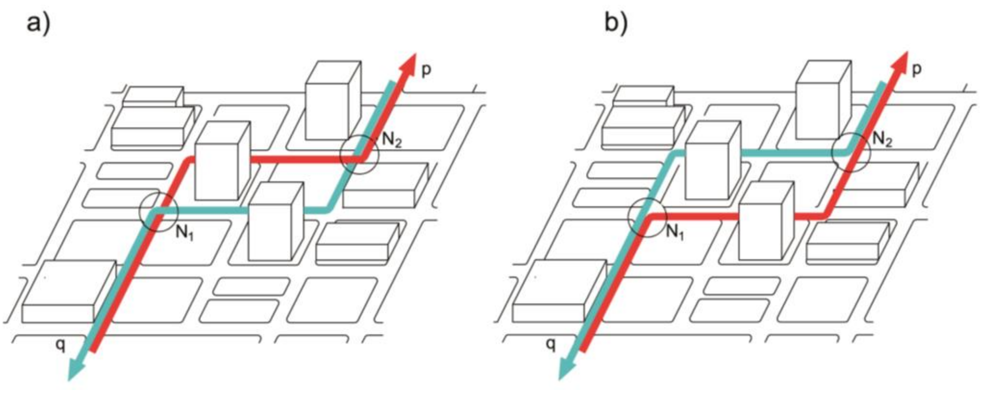

Figure 1: Example of unnecessary traversing traffic flows and possible solution

Unnecessary traversing of traffic flows can occur at one or more critical points, usually there are two points of traversing between opposing flows. Unnecessary traversing which occurs in one point is very rare in real transport environment [1].

This phenomenon of unnecessary traversing can be identified easily if one is conducting a round trip between two zones using a most likely paths and on the return trip traverses its own trajectory from the initial trip. This is the main indication that this is not an isolated case and that the other drivers within the same network perform the same actions, and this could be the indicator that that the organization of traffic flows is forcing the drivers to do so. In dependence with the number of vehicles traversing in one point in a period of time this problem can then be pinpointed and addressed. By using several methods described in [1-4,8], it is possible to find a solution for avoidance of phenomena of unnecessary traversing among the two pairs of traffic flows. Unnecessary traversing are quite common in traffic networks [1]. Figure 2 shows the example of unnecessary traversing of traffic flows between zones (1) and (2) and zones (3) and (4). In this example, unnecessary traversing occurs at two traversings and at four critical points per traversings which sums to in total of eight critical points.

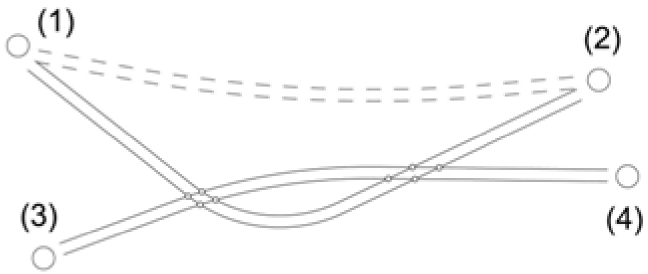

Figure 2: Unnecessary traversing of traffic flow at traversings

Analysis of the amount of these unnecessary traverses of vehicles on the road network can be conducted by utilizing information about the itineraries of the individual vehicles gathered from fleet management and tracking systems [4]. By monitoring the flow of vehicles and deviations in their speed it is possible to determine the frequency and intensity of self-traversing of traffic flows on the observed road network. This research focuses on the possibility of developing specific algorithms for automatic identification of unnecessary traversing based on gathered input data. Orientation of street network and proper directions of one-way streets have a particularly great importance in decreasing the phenomenon of unnecessary traversing of traffic flows [7]. For instance, it is clear that in the two-way street, no one will drive on the left side. But, in the case of wrong orientation of the pair of one-way streets this phenomenon will occur, as well as in the path decision process in case of parallel two-way streets.

3. RESEARCH DESCRIPTION

We have been granted to utilize one month of historical data from the largest "fleet management system" provider in Croatia. Using a GNSS device installed in the vehicle, data was collected about current position, time and speed of each vehicle in the vehicle fleet. Based on the data collected it is possible to determine the path and trajectory of individual vehicles. Since GNSS enabled device records information about the current position, time and speed of the vehicle at intervals of 5-60 second, the vehicle trajectory can be represented as points on the observed transport network.

The recorded vehicle trajectories were reconstructed from point features on the entire traffic network and that gave us an extremely precise insight into the relations of the traffic flows. This level of precision was not achievable by classical methods described in [3]. Based on the study of these flows it is than possible to conduct precise analysis and to optimize the relations among traffic flows. Spatial analysis of vehicle trajectories was conducted in Quantum GIS application. Quantum GIS application allows storage, editing and visualization of any geospatial data. Geospatial information database which stores road traffic data must consist of two logical sections. First section is reserved for static data and stores information about road infrastructure and objects, which represents the constant value. Static data is used to visualize road network map as a separate representation layer and is located under the layer with the traffic data. Second section of the database is reserved for dynamic data about traffic flow characteristics, which is updated and stored in real time from information gathered by sensors (GNSS devices) which are located in the vehicles and are "floating" within the traffic network [2] [5].

After conversion of the collected data in the appropriate shape format and their import into GIS application, it is possible to plot trajectories of all vehicles in the fleet in the form of point feature layer. Attributes are assigned to each dotted feature, including the vehicle identification number, the current position of the vehicle, the current date and time and the current vehicle speed. Data about the road network is also imported into a GIS application in the form of linear data layer. By overlying these two layers of data it is possible to obtain a detailed view of trajectories for all vehicles on the observed transport network. Based on the attribute tables in GIS, the imported data about vehicle trajectories can be filtered by defined attribute values which can be used to filter the trajectories of individual vehicles or a defined group of vehicles within a defined period of time**.** This enables the identification of points of unnecessary traversing and self-traversing of vehicle trajectories. Points of unnecessary self-traversing of vehicle trajectories can be detected by comparing the values of attributes of individual spatial point features. Thereby, points of unnecessary self-traversing of vehicle trajectories can be defined as points where a vehicle crosses its own path. At points of unnecessary self-traversing of vehicle trajectories, groups of point features of the same vehicle with larger differences in the values of the attributes of time can be identified, while the values of attributes that describe the current position of the vehicle are roughly equal.

In this paper, in order to determine the points of unnecessary traversing and self-traversing of traffic flows on the Zagreb road network, data about the trajectories of individual vehicles in in a commercial fleet were observed. Based on satellite tracking and positioning of individual vehicles in the fleet, data about the current position (longitude, latitude and altitude), time and speed of each individual vehicle were collected. Number of points of traversing and self-traversing of traffic flows on the observed road network is determined based on the analysis and comparison of the measured values of geographic coordinates, the current time and speed of individual vehicles in the fleet. Figure 3 a) shows an example of traversing point of two vehicle trajectories at the isolated traversing. In the observed traversing point Tp, two vehicles V1 and V2 cross their paths at roughly equal geographic coordinates xp, yp, and it is assumed that the time interval between the passage of first and second vehicle through traversing point is relatively short. On this basis, it can be concluded that the traversing of the vehicle trajectories exists in point Tp if the following mathematical terms are met:

$$\Delta_{xTp} = x_p - x_1 < \varepsilon \qquad \Delta_{yTp} = y_p - y_1 < \varepsilon$$
$$\Delta_{xTp} = x_p - x_2 < \varepsilon \qquad \Delta_{yTp} = y_p - x_2 < \varepsilon$$
$$t_1 \cong t_2$$

Where:

- xp, yp - longitude and latitude of traversing point Tp
- x1, y1 - the measured coordinates of vehicle V1 during its passage through the traversing point Tp
- x2, y2 - the measured coordinates of vehicle V2 during its passage through the traversing point Tp
- t1, t2 - time of passage for vehicles V1 and V2 through the traversing point Tp
- ε - allowed deviation of the measured coordinates from the actual geographic position of the vehicle during satellite positioning of vehicles in urban areas

Points of self-traversing of traffic flows were determined based on the comparison of the values of spatial and temporal attributes of individual vehicles in the fleet. Point of self-traversing of vehicle trajectories can be defined as the point where vehicles have roughly equal values of spatial attributes (longitude and latitude) and a greater difference in the time attribute.

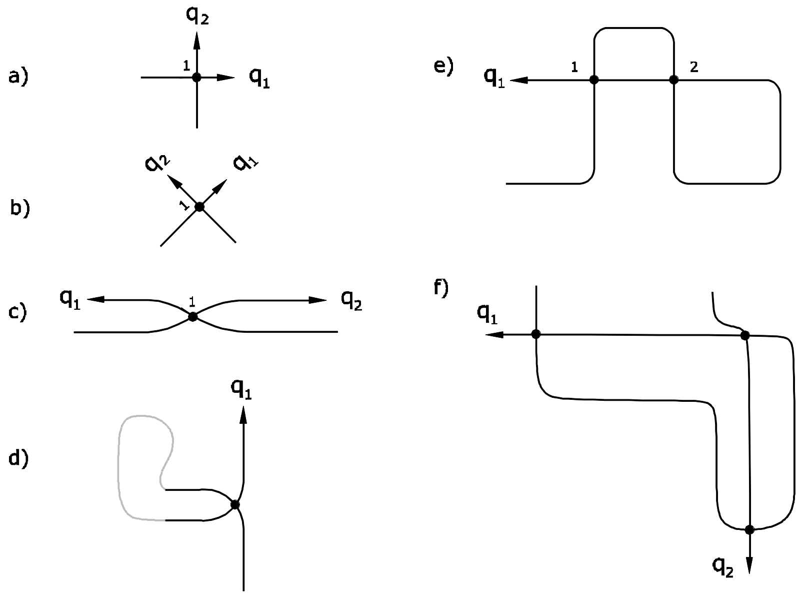

Figure 3: Examples of unnecessary traversing and self-traversing of traffic flows on the road network.

Figure 2 - e) shows the simplified case of self-traversing of individual vehicle trajectory at the two points in the road network. During the passage of vehicle through the first point of self-traversing T1 at point in time t1, the vehicle is located at coordinates x1,y1, while during the passage of vehicle through the second point of self-traversing T2 at point in time t2 vehicle is located at coordinates x2,y2. After the change of direction the observed vehicle intersects its path at the point T2 at point in time t3 and the coordinates x3,y3. At point in time t4 vehicle self-intersects its trajectory at the location of point T1 with coordinates x4,y4. Since there are two points of self-traversing, the vehicle must pass twice through the points T1 and T2 respectively. Because the vehicle passes through the point T1 and T2 twice, the maximum difference between the pairs of coordinates (x1, y1), (x4, y4), (x2, y2) and (x3, y3) must not be greater than the maximum allowed deviation of the measured vehicle position from the actual geographical coordinates during satellite positioning in urban area. On the other hand attribute of time must be different during the first and second vehicle passage through the point T1 and T2 respectively. To avoid the wrong identification of self-traversing point in conditions of congested traffic flow when the vehicle may be located at the roughly equal geographic position for a longer period of time, it is necessary to take into account the vehicle speed parameter in the period between the first and second vehicles passage through the point of self-traversing. So the self-traversing of vehicle trajectory exists at point T1 if the following mathematical terms are met:

$$\Delta_{xT1} = x_4 - x_1 < \varepsilon \qquad \Delta_{xT2} = x_3 - x_2 < \varepsilon$$

$$\Delta_{yT1} = y_4 - y_1 < \varepsilon \qquad \Delta_{yT2} = y_3 - y_2 < \varepsilon$$

$$t_1 \neq t_4 \quad V_1, V_4 \neq 0 \qquad t_2 \neq t_3 \quad V_2, V_3 \neq 0$$

Where:

- $x1$, $y1$ – lon. and lat. of vehicle position during the first passage through the point T1
- $x2$, $y2$ – lon. and lat. of vehicle position during the first passage through the point T2
- $x4$, $y4$ – lon. and lat. of vehicle position during the second passage through the point T1
- $x3$, $y3$ – lon. and lat. of vehicle position during the second passage through the point T2
- $\Delta xT1$, $\Delta yT1$, $\Delta xT2$, $\Delta yT2$ - the difference between the measured longitude and latitude values
- during the first and second passage of vehicle through the point T1 and T2 respectively
- V1, V2, V3, V4 - the current speed of the vehicle during the first and second pass through the point T1 and T2
- ε - allowed deviation of the measured coordinates from the actual geographic vehicle position during satellite positioning of vehicles in urban areas

Since during the self-traversing of vehicle trajectory in the time point t4, vehicle must return to roughly equal geographic position ($x1 + \Delta x$, $y1 + \Delta y$) where it was located at point in time t1, it can be concluded that point of self-traversing exist if comparation of the spatial and temporal attributes of individual vehicles shows that specified mathematical conditions are met. Other examples of unnecessary traversing and self-traversing of traffic flows on the road network are shown in Figure 2 b), c), d) and f).

GIS application also allows implementation of complex stochastic analysis which takes into account the variability of values in observed attributes, and other features of traffic flow on the observed road network. After identification of points of the unnecessary traversing of vehicle trajectories, it is necessary to define and prioritize remediation measures. Remediation priorities can be determined based on the determined intensity of unnecessary traversing at certain spots of road network. Based on the analysis of the attributes of time and speed of individual vehicles it is possible to determine the average waiting time of vehicles at these points. A detailed statistical analysis of the relationship between the trajectories of individual vehicles and spatial characteristics of the observed traffic network can be conducted to determine the effect of certain points of unnecessary traversing on the reduction of traffic flow in the surrounding elements of the road network. It is also possible to carry out an analysis of the causes of particular points of the unnecessary traversing. After detection of position and number of traversing and self-traversing points in the observed road network the intensity of traversing and self-traversing of traffic flows at individual points can be determined based on the following three mathematical expressions [1]:

$$I_{PR(t)} = \sum_{1}^{N_{pr}} \min(p,q) \left[\frac{voz}{h}\right]$$

$$I_{PR(t)} = p + q \left[\frac{voz}{h}\right], \forall p,q > 0$$

$$I_{PR(t)} = \sum_{1}^{Npr} \sqrt{pq} \left[\frac{veh}{h}\right], \forall p,q > 0$$

Where:

I_{PR} (t) - the intensity of traversing or self-traversing of traffic flows [veh/h]

p - Primary traffic flow volume [veh/h]

q - Traversing traffic flow volume [veh/h]

N_{pr} - the number of traversing and self-traversing points

In this paper analysis of individual vehicles trajectories in the traffic flow were conducted on the Zagreb road network. One of the most critical point of traversing and self-traversing of traffic flows was determined in Lučko junction which is located at the southwestern part of the road network in the city of Zagreb. At the area of Lučko junction a total of 5 points with a high degree of traversing and self-traversing of traffic flows was detected. Figure 4 shows the analyzed area with five determined points of traversing and self-traversing of individual vehicles trajectories. Critical point (red) is the point on which the highest intensity of at-grade traversing and self-traversing of traffic flows is determined. Points marked yellow have been discarded since traffic flows are running on separated grades

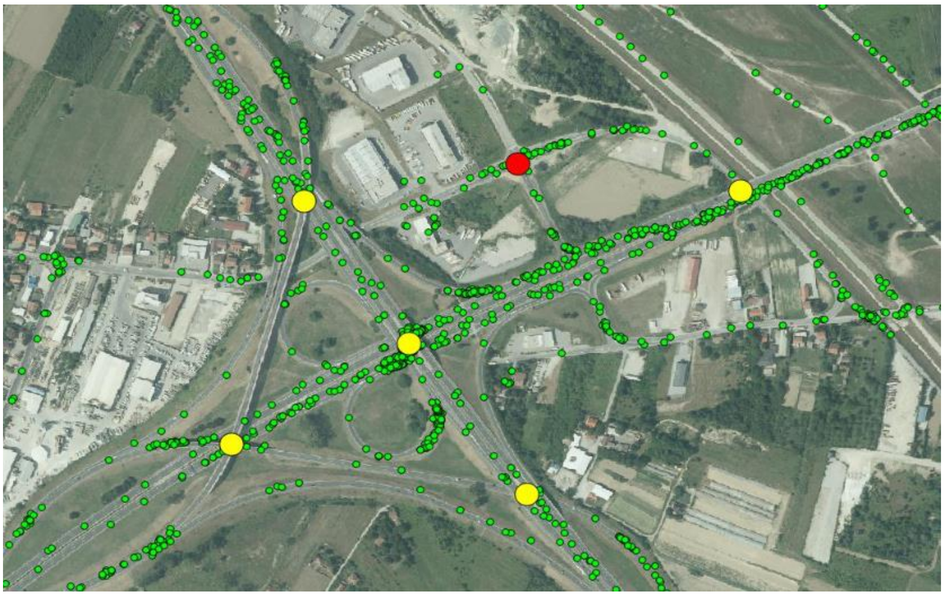

Figure 3: Determined of traversing and self-traversing points of individual vehicles trajectories at Lučko junction.

Traffic flows in the area of Lučko junction are mainly directed towards business and commercial zone located in the vicinity. Traffic queue that form at the junction is often few hundred meters long and occurs due to the unnecessary traversing of traffic flows that can be avoided (Figure 4 - a)). Problem of unnecessary traversing and self-traversing of traffic flows can be solved by upgrading the north ramp on the node (Figure 4 - b)). Another solution is to build additional ramps that would separate traffic flows from Zagreb to Lučko before junction, in order to avoid unnecessary traversing of traffic flows (Figure 4 - c)).

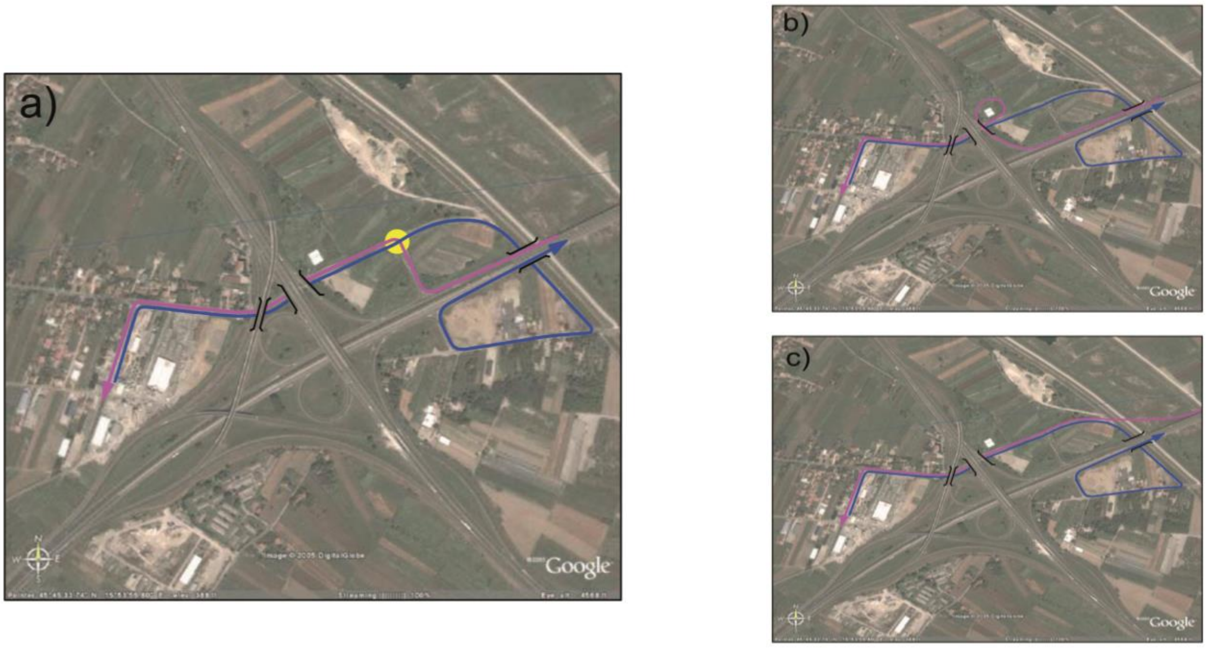

Figure 4: Detected Problem and possible solution Lučko junction

4. DISCUSSION AND CONCLUSION

The phenomenon of frequent unnecessary traversing of the driving vehicles, depending on the intensity, may influence the throughput capacity of the traffic network, and especially the nodes. The most common causes of unnecessary traversing of traffic flows include improper directing of one-way streets, improper directing of traffic flows by informative signalization, inadequate regulation of traffic flows (frequent and unnecessary prohibitions and liabilities) three-phase and even four-phase signal traffic regulation, inadequate traffic and urban planning as well as inadequately designed traversing, particularly the grade-separated ones. The elimination of the unnecessary traversing of traffic flows reduces the number of traffic accidents and increases throughput capacity of traversing [9]. The average speed of vehicles also increases due to greater capacity of the road network segments. By reduction of unnecessary traversing of traffic flows pollution is also decreased. Optimal organization of traffic flow in the road network also results in lower costs in exploitation of individual vehicles and public transit services. Consequently, existing road infrastructure is optimally exploited and therefore less investment in infrastructure is required. The proper selection of the itinerary from the origin to the destination in cities, along with systemic application of different measures, may increase the throughput capacity of the traffic network by 10-30% without having to construct any new network sections. Modern satellite navigation can be very useful in determining the vehicle itinerary, and can also provide the drivers with the suggestions for selecting the optimal route in order to reduce the unnecessary traversing of the traffic flows, especially on the busiest traversing. By recording and noting the trajectories of each individual vehicle during its usage by means of satellite navigation it is possible to determine the locations and intensities of unnecessary traversing of the traffic flows. Analysis of identified points of unnecessary traversing on the observed road network also allows detection of so-called critical traversing spots with maximum intensity of traversing. Therefore, further development and research should be focused on creating algorithms for automatic identification of unnecessary traversing based on gathered input data as well as providing the powerful decision making support tool which may integrate all available data about the road network.

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